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STRENGTH DETERMINATIONS OF LUPIN MINE ROCKS

B. Gorski

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STRENGTH DETERMINATIONS OF LUPIN MINE ROCKS

by

B. Gorski*

ABSTRACT

Laboratory tests were conducted on drill cores originating from diamond drilling activity at Lupin Mine, located on the southwest shore of Contwoyto Lake in the Northwest Territories. The results of strength and deformation properties of 30 test specimens are presented in this report.

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*Rock Mechanics & Development Technologist, Canadian Mine Technology Laboratory
Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Canada

Keywords:

Brazilian tensile strength, multi-stage triaxial test, uniaxial compressive strength, axial displacement control, post-failure, residual strength, confinement pressure, peak strain, modulus of elasticity, Poisson's ratio, Hoek and Brown failure criteria

CALCUL DE LA RÉSISTANCE DES ROCHES DE LA MINE LUPIN

par
B. Gorski*

RÉSUMÉ

Des essais de laboratoire ont été menés sur des carottes provenant de forages au diamant dans la mine Lupin située sur la rice sud-ouest du lac Contwoyto dans les Territoires du Nord-Ouest. Les résultats des essais de résistance et de déformation de 30 éprouvettes sont présentés dans ce rapport.

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* Technicien en mécanique et en évolution des roches, Laboratoire canadien de technologie minière, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa, Canada

Mots clés:

Essai brésilien de résistance à la traction, essai tiaxial fractionné, résistance à la compression uniaxiale, contrôle des déplacements axiaux, après rupture, résistance résiduelle, pression de confinement, déformation maximale, module d'élasticité, coefficient de Poisson, critère de rupture de Hoek et Brown

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1. INTRODUCTION

MRL received from Echo Bay Mines Limited, drill core samples originating from Lupin Mine. An MTS 815 Rock Mechanics Test System was used to conduct uniaxial and multi-stage triaxial tests, and an ELE compression press to conduct Brazilian tensile tests. Triaxial tests were conducted using computer control on the MTS servo-hydraulic test system. The results of strength and deformation property tests are presented in this report.

2. TEST PROCEDURE

SPECIMEN SELECTION

Triaxial, uniaxial and Brazilian tests were conducted on rock specimens cut from each received core. Specimens have been identified according to the rock type received from the mine site, for example;

Example P3

P - P for phyllite, Q for quartz-metagreywacke and O for Sulphide iron

3 - sample number

The specimen location, test type, dimensions and density, δ, of each tested specimen, are listed in Table 1.

SPECIMEN PREPARATION

Rock core sample specimens selected for uniaxial and triaxial tests were prepared with length to diameter ratios of 2:1 to 2.5:1. Brazilian tensile strength specimens were prepared with length to diameter ratios of 1:2. All specimens were lapped to within specified MRL tolerances, oven dried, weighed and dimensioned. Prior to testing, planes of discontinuity, if any, or potential weaknesses were highlighted with ink. Specimen preparation was performed according to the procedures used at MRL [1,2].

BRAZILIAN TEST

Test specimens were loaded to failure using a 2000 kN ELE compression press. The test procedure conformed to ISRM suggested methods [4].

CONVENTIONAL UNIAXIAL TEST

Test specimens were loaded to failure uniaxially at a rate of 0.75 MPa/s.

MULTI - STAGE TRIAXIAL TEST

The specimen was brought to equilibrium, under load control mode, by the simultaneous application of axial load and confining pressure, at the rate of 0.75 MPa/s. After the desired confining pressure of the first stage was reached, the axial loading continued, at the rate of 0.75 MPa/s while the confining pressure was kept constant. When the specimen axial load was 60 kN greater than the equilibrium load, the axial load was then reduced by 20%. The control mode was then switched over to axial displacement control. The test was continued, at an axial displacement rate corresponding to an axial stress rate of 0.75 MPa/s until initial failure occurred, as detected by an axial load drop. The axial displacement rate was then stopped and then reduced by 33% of total axial displacement.

The desired confining pressure of the second stage was then applied and loading continued according to the same method just outlined for the first stage. The procedure was subsequently repeated for each predetermined increment of confining pressure. Confining pressures of 10, 20 and 30 MPa were used.

The confining pressure of the last stage was held through the peak strength until the residual strength was visually established, as indicated by a plateau in the stess/strain curve recorded by the X-Y recorder. The specimen was then further axially displaced an additional 0.5 mm, while the confining pressure was linearly reduced to zero within a time period of 60 seconds. This last phase of the test was required for residual strength data. Residual strength data was not determined for the sulphide iron as post-failure test control was not achieved.

DATA ACQUISITION/REDUCTION

Uniaxial and triaxial data were scanned and stored digitally on hard disk using a PDP 11/73 computer every 3 seconds. Analog signals from the load cell, circumferential extensometer, axial LVDTs, and confinement pressure were scanned. Real time plots of load versus axial displacement were obtained using a HP7046B X Y1 Y2 pen recorder wired to a MTS 448.85 controller.

The raw signals were reduced to engineering units and stored on hard disk for later recall. Measurements from axial LVDTs were corrected for end platen compression in the sensing gauge length. Reduced data were transferred to a VAX 750 computer for specimen material constant determinations. Hard copy plots of triaxial test results for report purposes were obtained using the DEC LVP16 pen plotter. A laser printer was used to provide hard copy plots of uniaxial test results. The DEC LA50 printer was used to provide hard copies of reduced triaxial data for analyses.

3. TEST RESULTS

TENSILE STRENGTH

The tensile strength results, σ_t, obtained by Brazilian test, are listed in Table 2.

UNIAXIAL COMPRESSIVE STRENGTH

The peak strain values, ϵ_{peak}, listed in Table 3, were determined by readings from the axial strain gauges. The uniaxial compressive strength results, Q_u, are also listed in Table 3.

Appendix A provides stress-strain plots using signals from axial strain gauges and circumferential strain gauges mounted on specimen surfaces.

ELASTIC CONSTANTS

The modulus of elasticity (calculated at 0.5 Q_u), E, and the Poisson's ratio, ν, were established in each uniaxial compressive test case using load cell, and strain gauge data. The obtained results are listed in Table 3.

TRIAXIAL COMPRESSIVE STRENGTH

The triaxial compressive strengths of the selected specimens were determined at successive confining stages of: 10, 20 and 30 MPa.

The stress-strain curve plots of the multi-stage triaxial tests are found in Appendix B. Axial strain measurements were made using LVDT units.

The results of the multi-stage tests are tabulated in Table 4.

HOEK AND BROWN M AND S MATERIAL CONSTANTS

Triaxial, uniaxial and brazilian test results were used in the Hoek and Brown failure criteria to determine the failure envelope for each rock type. Table 6 contains the derived material constants, m and s. Figures 1 to 3 depict the Mohr circle plots for each of the rock types. The method of analyses is limited to triaxial strengths that exceed $3.4\sigma_3$.

4. OBSERVATIONS

The geological classification of different rock core units are listed in Table 5. For each rock type tested, triaxial strengths increased with increasing specimen density and decreased with the presence of existing planes of weakness. Specimens increased in triaxial strength with increasing confining pressure. The specimens behaved elastically prior to peak strength.

5. REFERENCES

1. Gorski, B. "The design and operation of a stiff triaxial assembly for post-failure rock property testing"; *Division Report MRP/MRL* 82-81(*TR*); CANMET, Energy, Mines and Resources Canada; 1982.

2. Gyenge, M. and Herget, G. "Pit slope Manual 3-2; Laboratory tests for design parameters"; *CANMET Report* 77-26; CANMET, Energy, Mines and Resources Canada; 1977.

3. Gorski, B. "A multi-use load system for rock testing";*Division Report M&ET/MRL* 86-25(*TR*); CANMET, Energy, Mines and Resources Canada; 1986.

4. Brown, E.T. "Rock characterization testing and monitoring"; *ISRM*; *Pergamon Press, London, England*; 211p; 1981.

Table 1 Specimen Selection Data

Sample Number	Depth (m)	Test Type	Length (cm)	Diameter (cm)	Density (Mg/m^3)
Q1		Uniaxial	8.622	3.525	2.70
Q2		Uniaxial	8.431	3.538	2.68
Q3		Triaxial	8.404	3.524	2.70
Q4		Brazilian	1.766	3.527	2.69
Q5		Triaxial	8.277	3.529	2.74
Q6		Triaxial	8.356	3.524	2.73
Q7		Brazilian	1.798	3.527	2.74
Q8		Brazilian	1.773	3.525	2.72
Q9		Brazilian	1.802	3.526	2.67
Q10		Brazilian	1.788	3.529	2.66
P1		Uniaxial	8.441	3.460	2.86
P2		Uniaxial	8.576	3.458	2.89
P3		Triaxial	8.576	3.457	2.88
P4		Brazilian	1.461	3.442	2.81
P5		Brazilian	1.486	3.439	2.81
P6		Brazilian	1.439	3.441	2.84
P7		Triaxial	8.506	3.441	2.88
P8		Brazilian	1.443	3.925	2.93
P9		Brazilian	1.441	3.434	2.96
P10		Triaxial	8.809	3.509	2.85
O1		Triaxial	9.129	3.517	3.27
O2		Triaxial	8.942	3.502	3.10
O3		Uniaxial	8.801	3.520	3.22
O4		Triaxial	9.168	3.508	3.34
O5		Uniaxial	8.976	3.488	3.14
O6		Brazilian	1.845	3.497	—
O7		Brazilian	1.934	3.523	—
O8		Brazilian	1.908	3.523	—
O9		Brazilian	1.905	3.523	—
O10		Brazilian	1.961	3.961	—

Table 2 Brazilian Tensile Strength

Sample Number	Depth (m)	Failure Load (kN)	σ_t (MPa)
Q4		10.11	10.32
Q7		11.20	11.44
Q8		16.19	16.49
Q9		13.27	13.28
Q10		16.73	16.86
mean			13.68
std. dev.			±2.94
P4		15.67	19.82
P5		18.57	23.11
P6		16.65	21.39
P8		16.65	21.34
P9		14.62	18.79
mean			20.89
std. dev.			±1.65
O6		40.94	40.40
O7		31.78	29.70
O8		22.32	21.14
O9		23.72	22.50
O10		27.97	25.79
mean			27.90
std. dev.			±7.73

Table 3 Uniaxial Compressive Test Results

Sample Number	Depth (m)	Q_u (MPa)	ε_{peak} (%)	E (GPa)	ν
Q1		167.50	0.47	46.02	0.41
Q2		168.62	0.42	52.36	0.44
mean		168.06	0.44	49.19	0.42
std. dev.		±0.79	±0.04	±4.48	±0.02
P1		100.73	0.21	47.97	0.14
P2		140.46	0.23	56.64	0.28
mean		120.6	0.22	52.30	0.21
std. dev.		±28.09	±0.02	±6.13	±0.10
O3		518.71	0.50	99.19	0.28
O5		376.74	0.20	102.91	0.19
mean		447.73	0.35	101.05	0.24
std. dev.		±100.39	±0.21	±2.63	±0.06

Table 4 Multi-stage Triaxial Test Results

Sample Identification		σ_3=10.0 MPa		σ_3=20.0 MPa		σ_3=30.0 MPa	
Sample Number	Depth (m)	σ_1 (MPa)	ε_{peak} (%)	σ_1 (MPa)	ε_{peak} (%)	σ_1 (MPa)	ε_{peak} (%)
Q3		250.73	0.62	293.31	0.72	320.54	0.83
Q5		162.64	0.47	190.73	0.56	222.57	0.75
Q6		169.66	0.39	190.01	0.44	213.48	0.55
mean std. dev.		194.34 ±48.96	0.49 ±0.12	224.68 ±59.43	0.57 ±0.14	252.20 ±59.36	0.71 ±0.14
P3		161.35	0.39	(145.73)	(0.41)	(165.90)	(0.52)
P7		190.77	0.38	207.51	0.44	224.26	0.53
P10		131.02	0.27	151.54	0.35	178.38	0.49
mean std. dev.		161.05 ±29.88	0.35 ±0.07	179.53 ±39.58	0.40 ±0.06	201.32 ±201.32	0.51 ±0.03
O1		668.79	1.04	—	—	—	—
O2		—	—	753.33	0.82	659.79	0.94
O4		—	—	—	—	696.85	0.89
mean std. dev.		668.79 —	1.04 —	753.33 —	0.82 —	678.32 ±26.21	0.92 ±0.04

Table 5 Geological Classification

Borehole		Rock Type	Depth Interval (m)
630		Quartzite - metagreywacke	82
630		Phyllite	11
630		Sulphide iron	2

Table 6 Hoek and Brown m and s material constants

Rock Type	Depth Interval (m)	σ_3 Range (MPa)	σ_t (MPa)	Q_u (MPa)	Q_c (MPa)	m	s	r^2	m_r	s_r	r_r^2
Quartzite (metagreywacke)	82	10.0-30.0	-13.68	168.06	148.16	6.81	1.00	0.94	1.29	0.00	0.60
Phyllite	11	10.0-30.0	-20.89	120.60	127.55	3.57	1.00	0.98	1.39	0.05	0.30
Sulphide iron	2	10.0-30.0	-7.73	447.73	515.26	16.78	1.00	0.82	-	-	-

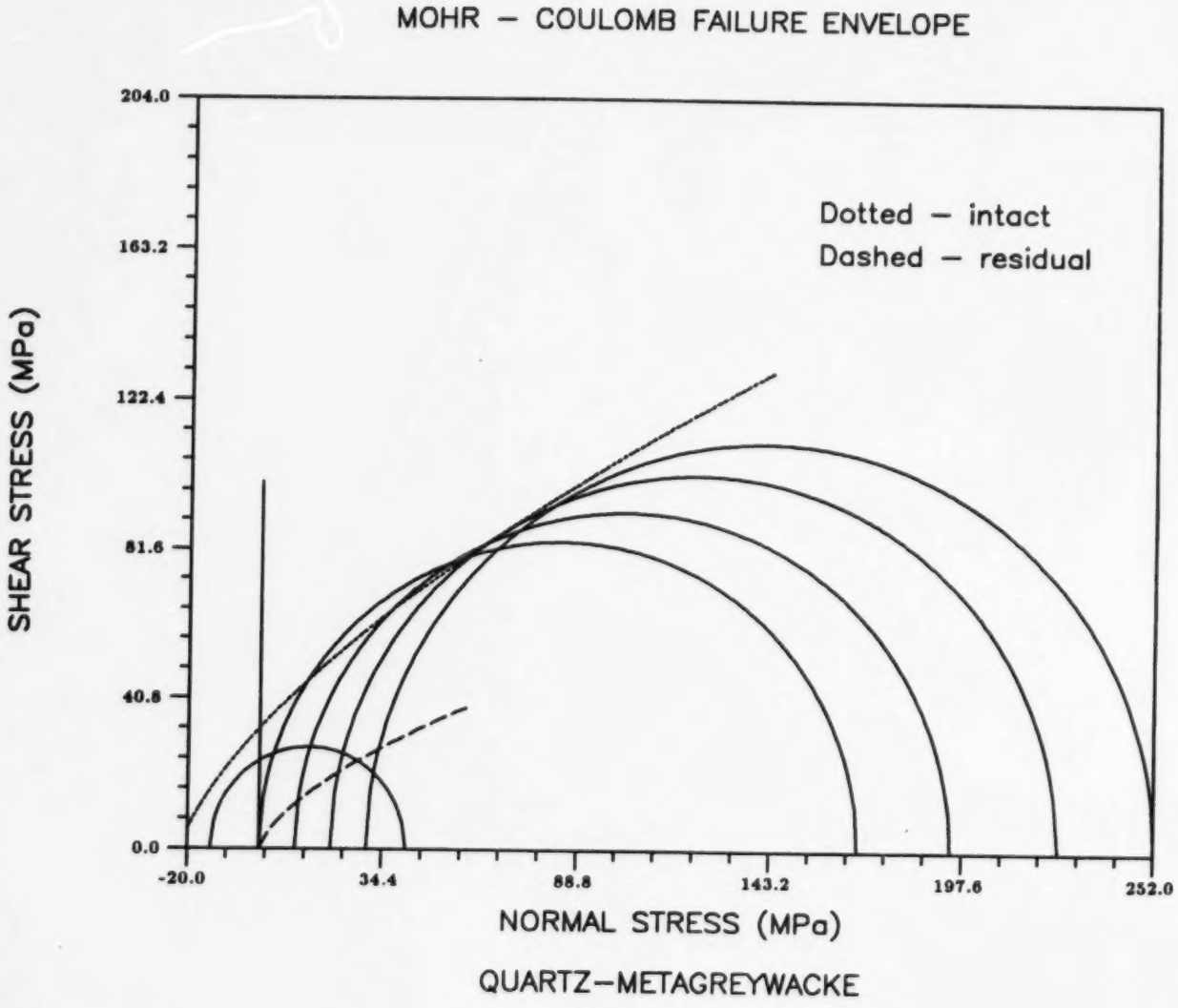

FIG.1 SPECIMENS Q1 - Q10

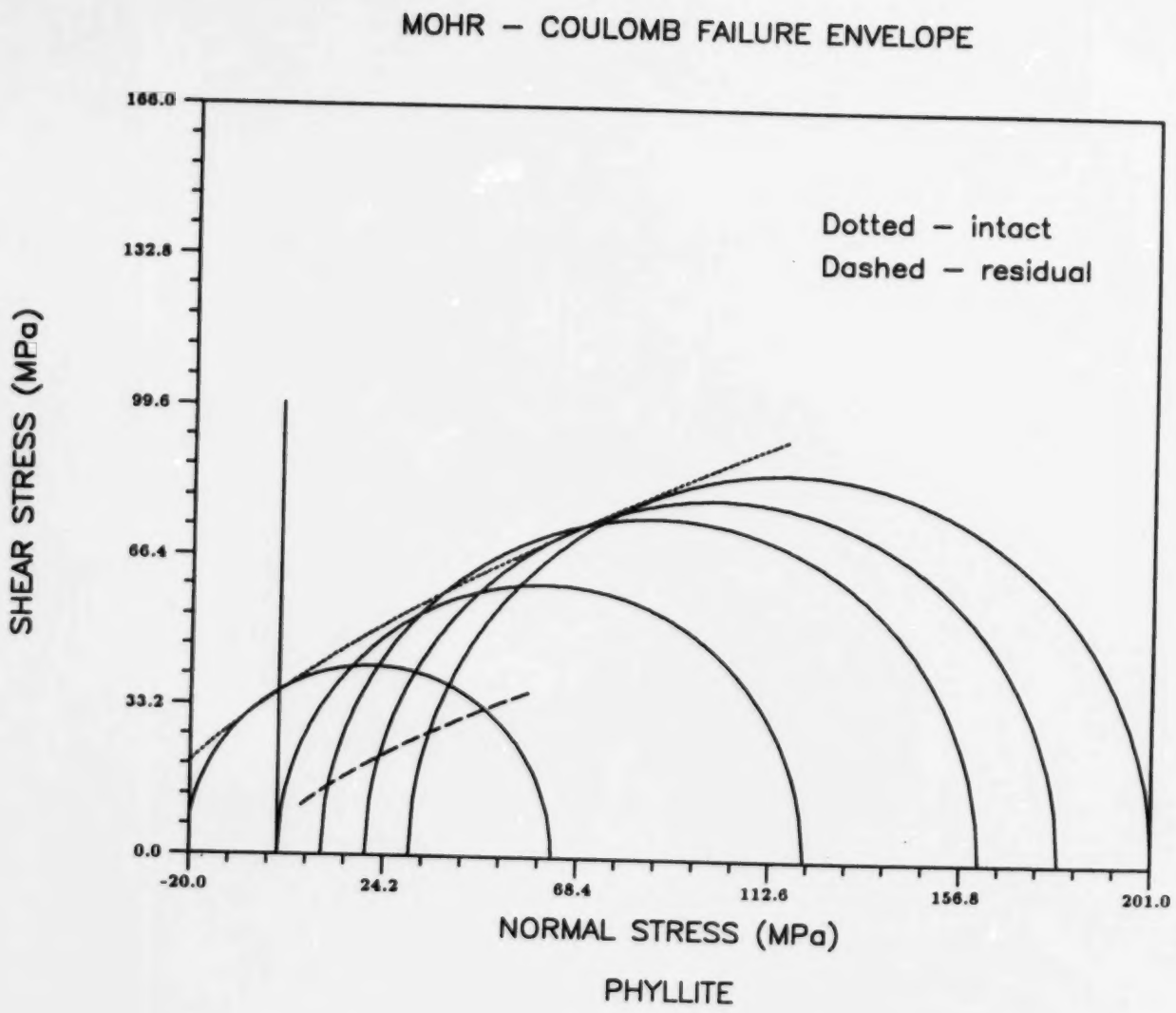

FIG.2 SPECIMENS P1 – P10

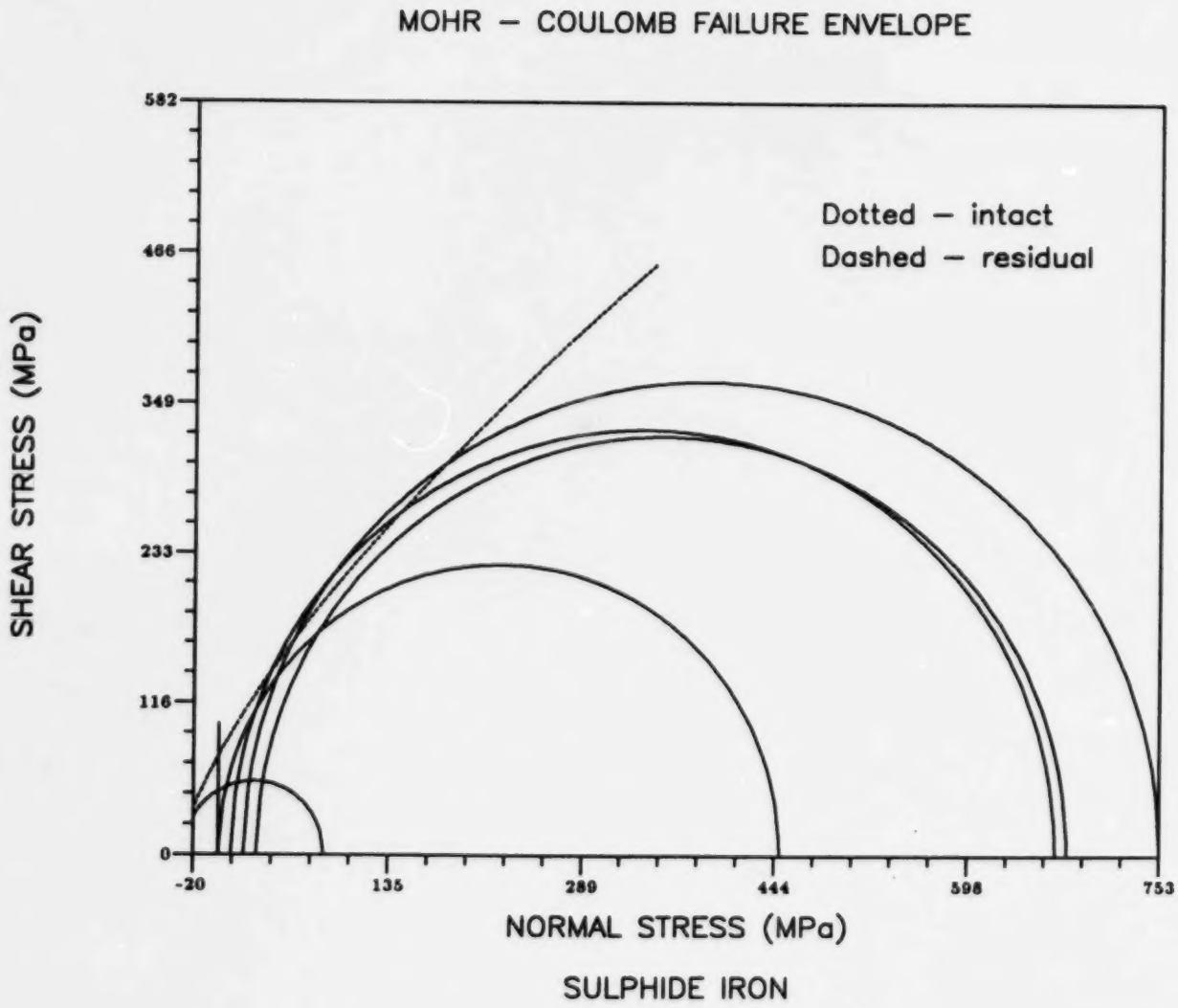

FIG.3 SPECIMENS 01 - 010

APPENDIX A

STRESS-STRAIN CURVES OF UNIAXIAL TESTS USING STRAIN GAUGES

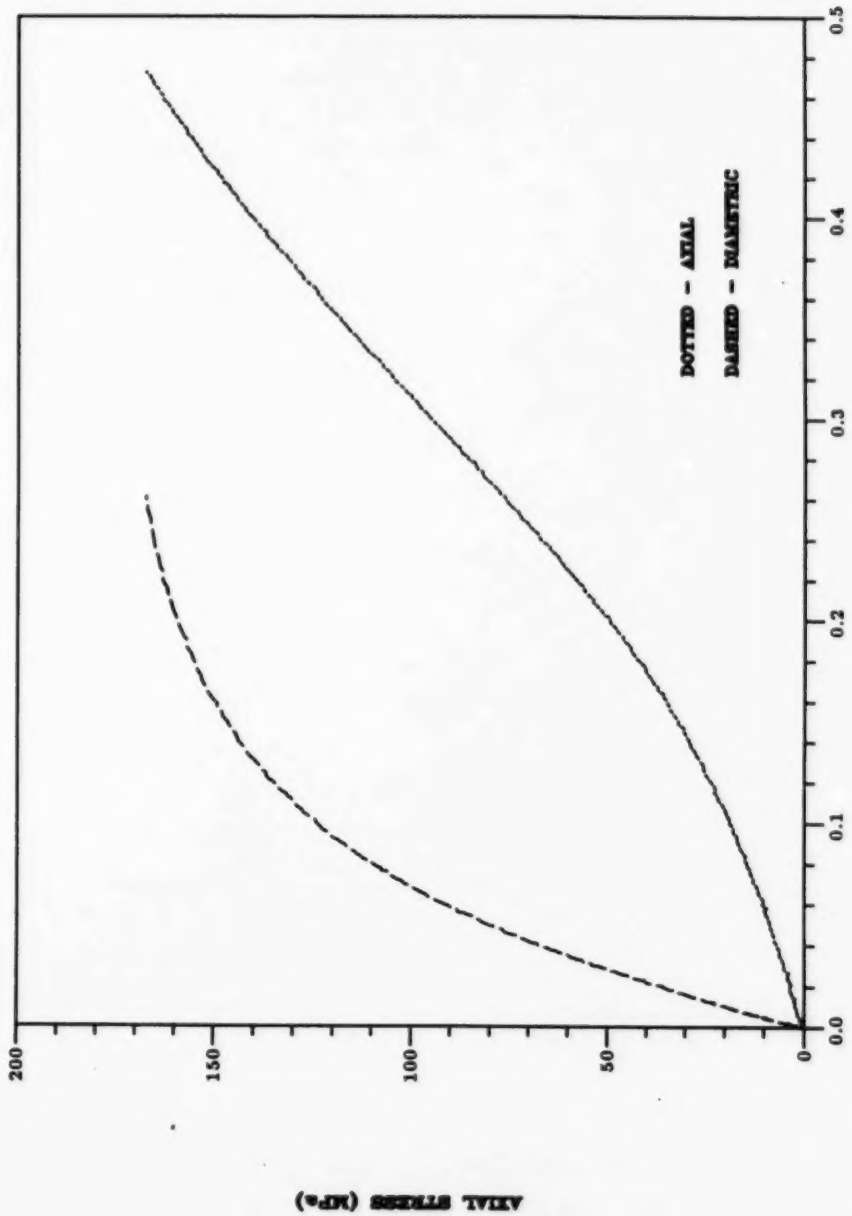

FIG.4 SPECIMEN Q1

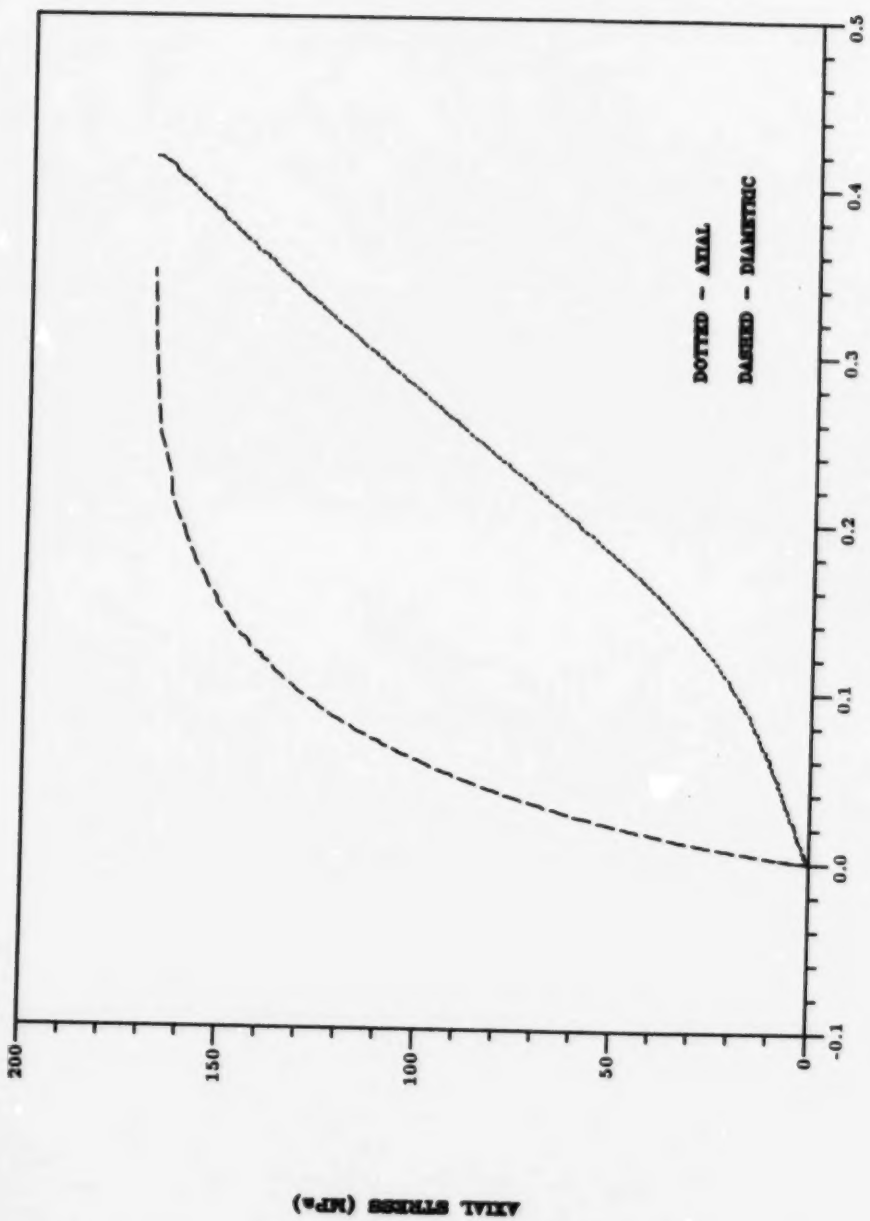

FIG.5 SPECIMEN Q2

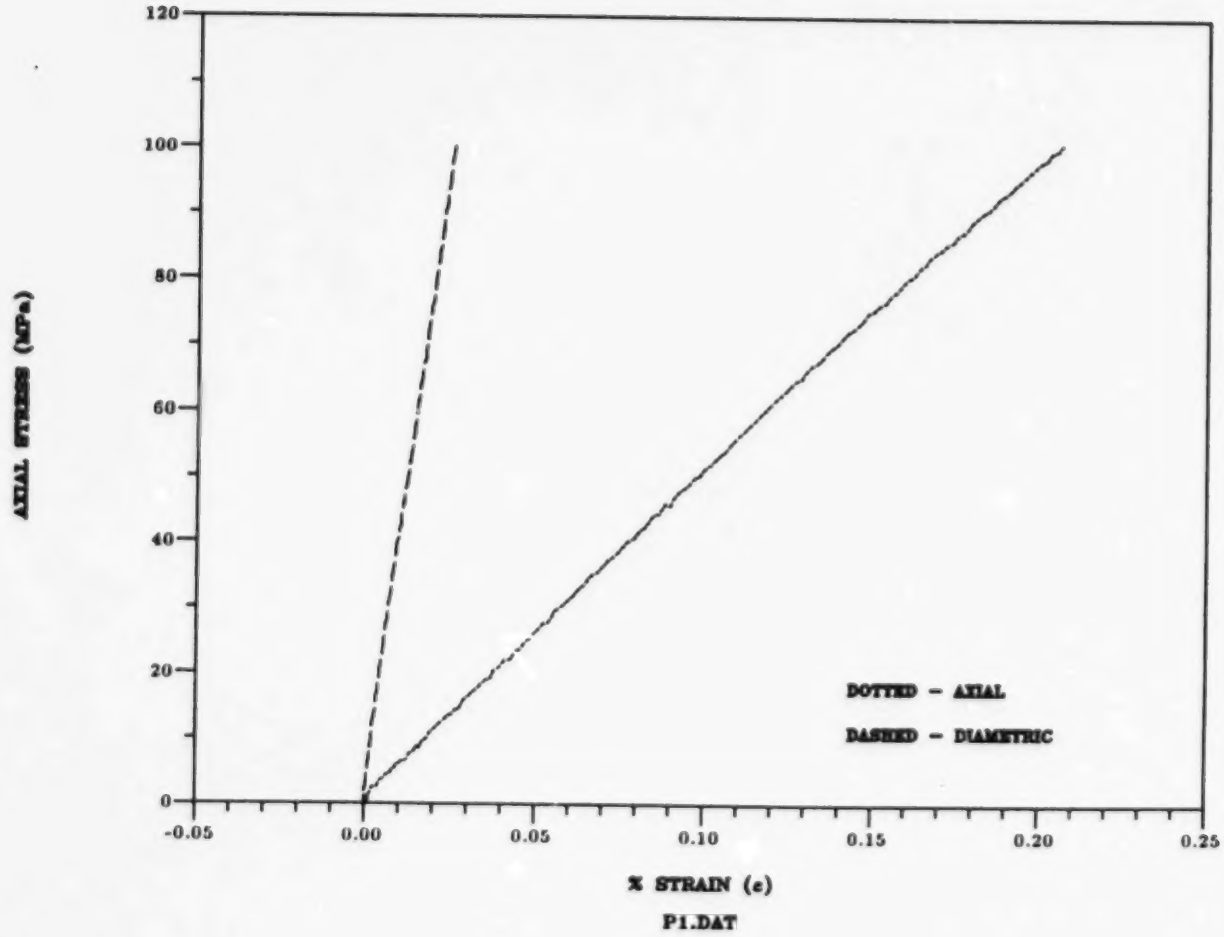

FIG.6 SPECIMEN P1

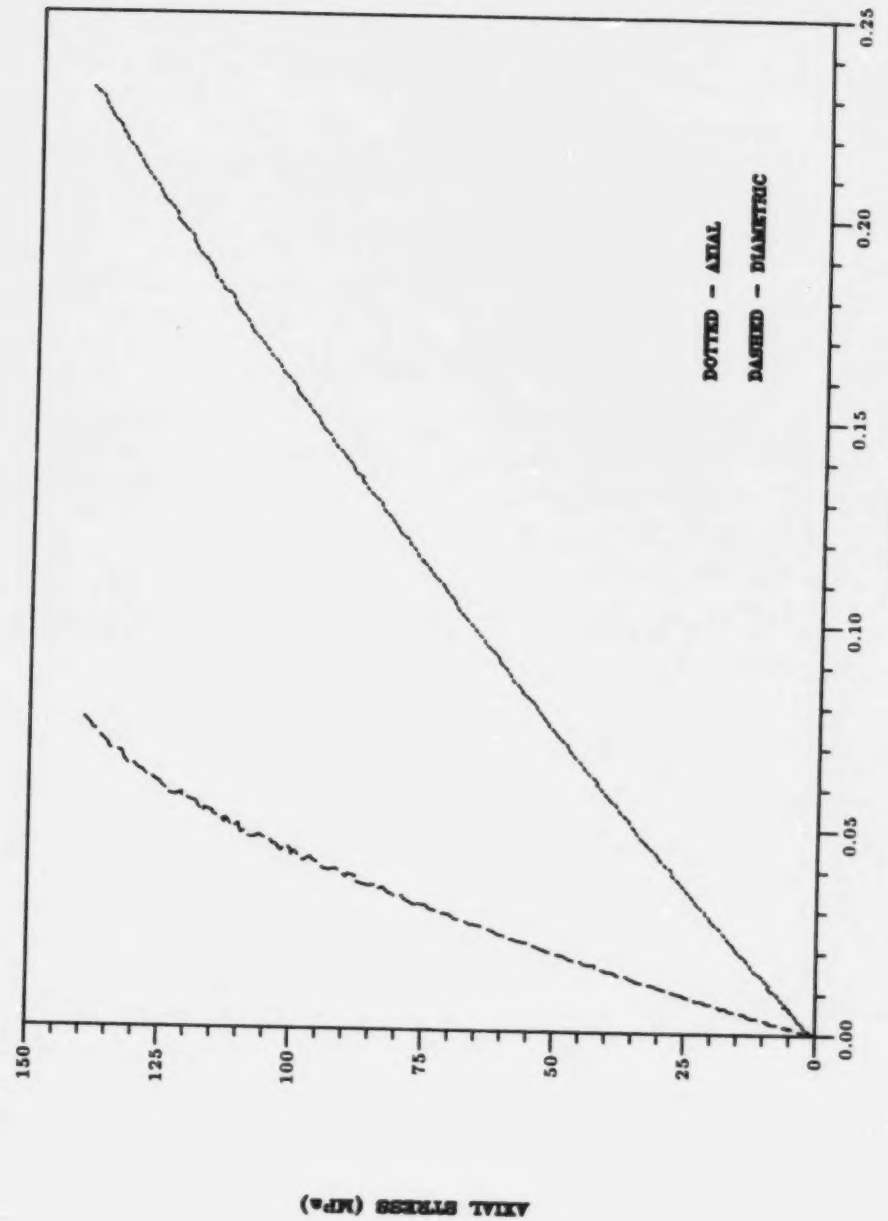

FIG.7 SPECIMEN P2

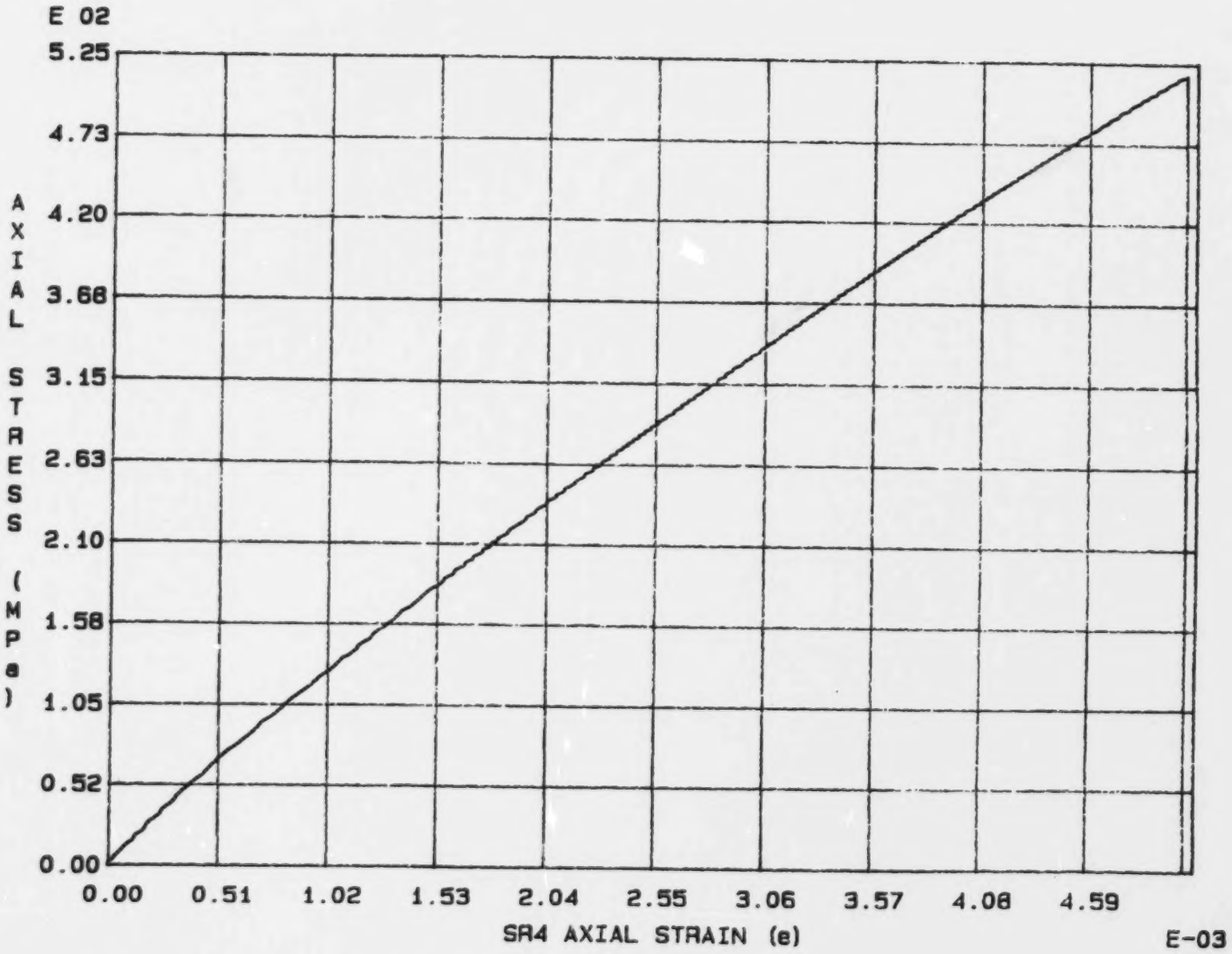

FIG.8 SPECIMEN 03

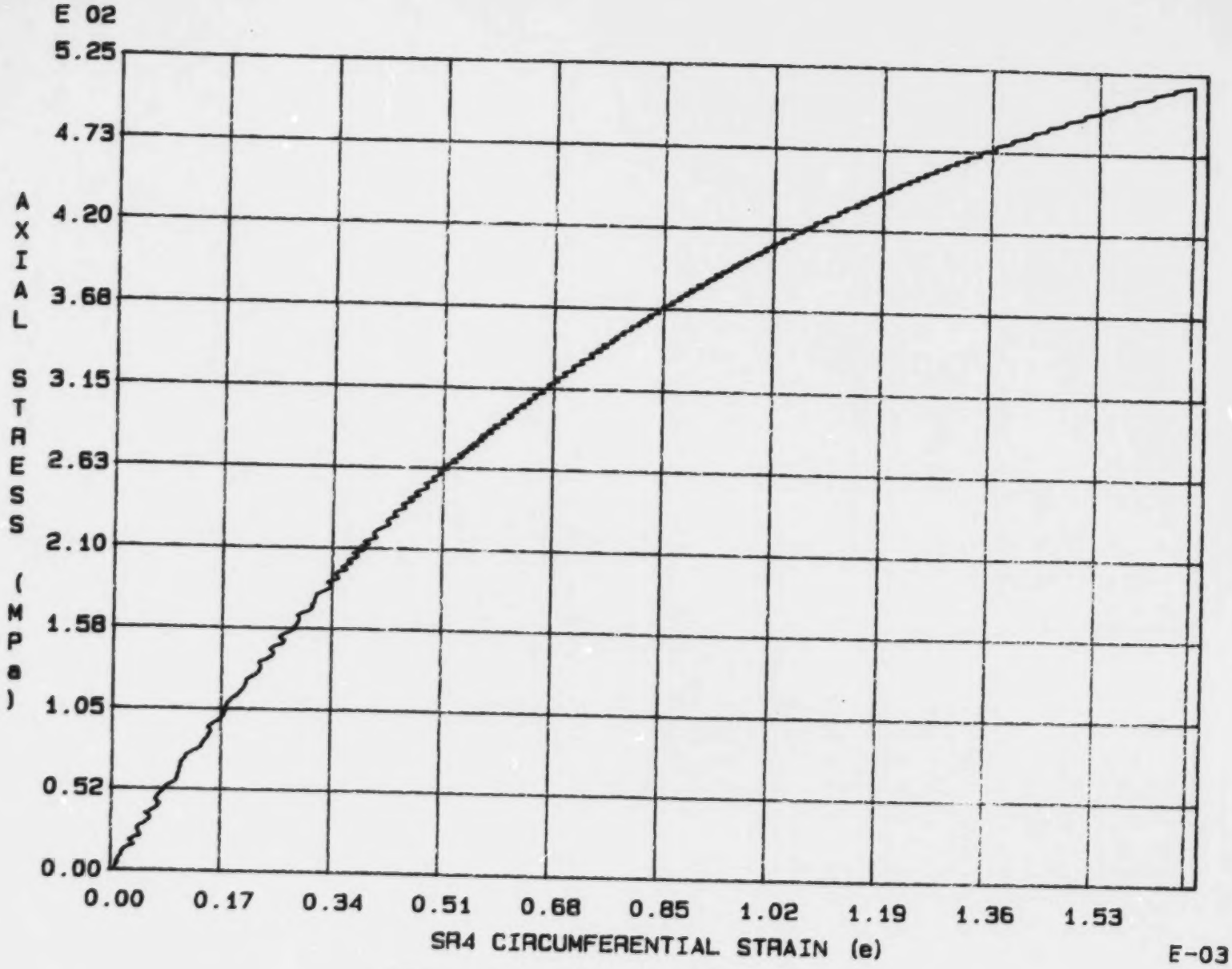

FIG.9 SPECIMEN 03

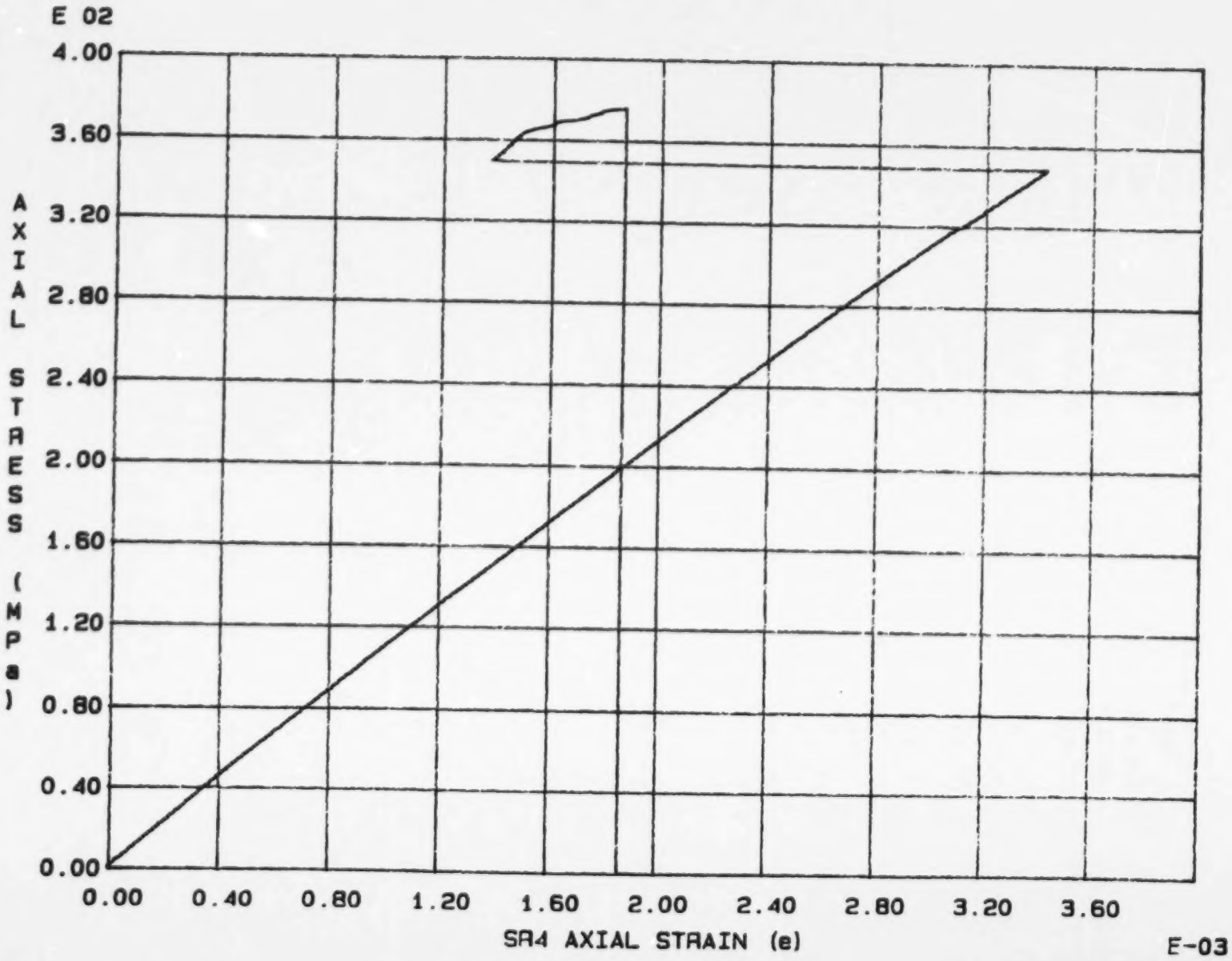

FIG.10 SPECIMEN 05

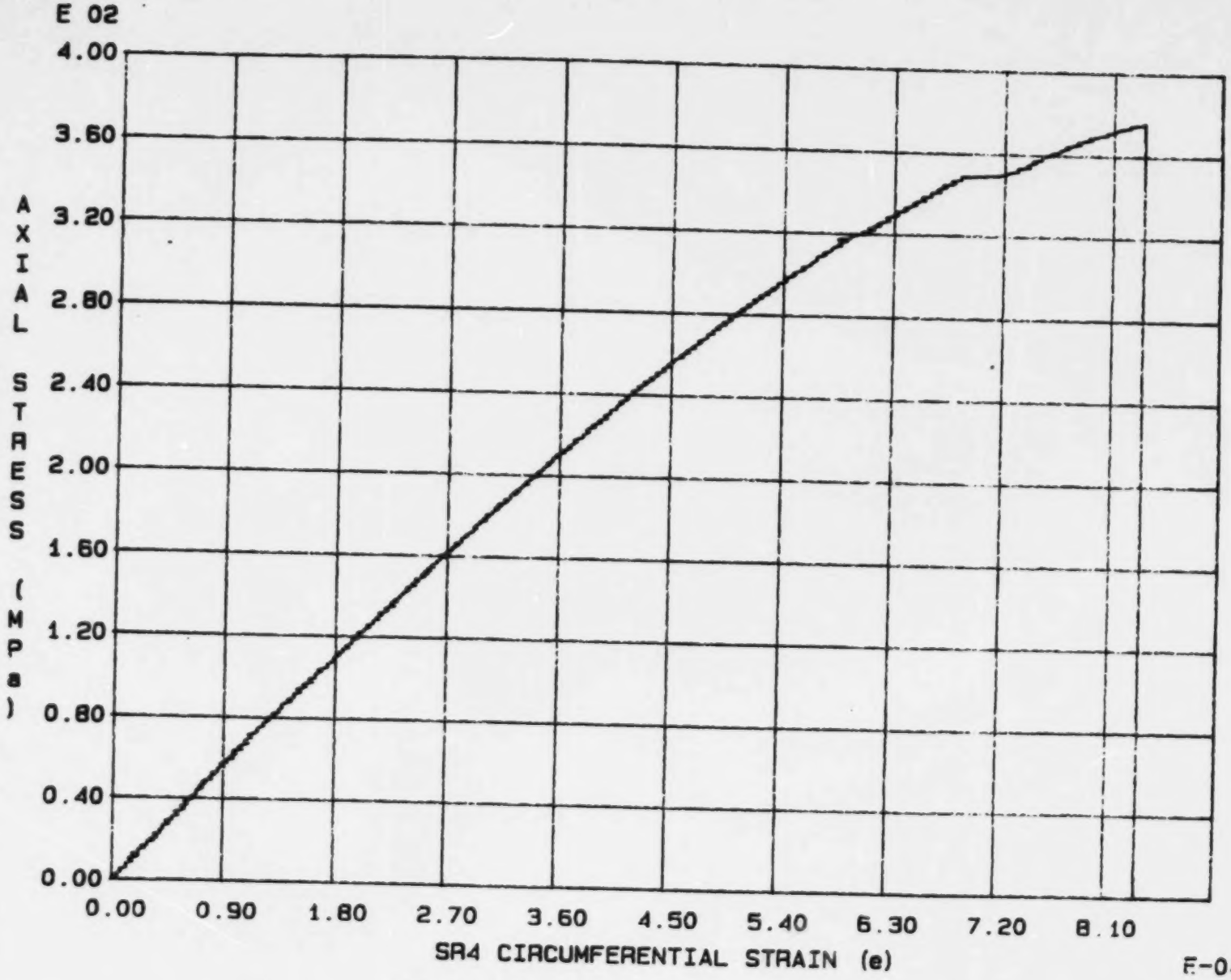

FIG.11 SPECIMEN 05

APPENDIX B

STRESS-STRAIN CURVES OF TRIAXIAL TESTS USING LVDTS

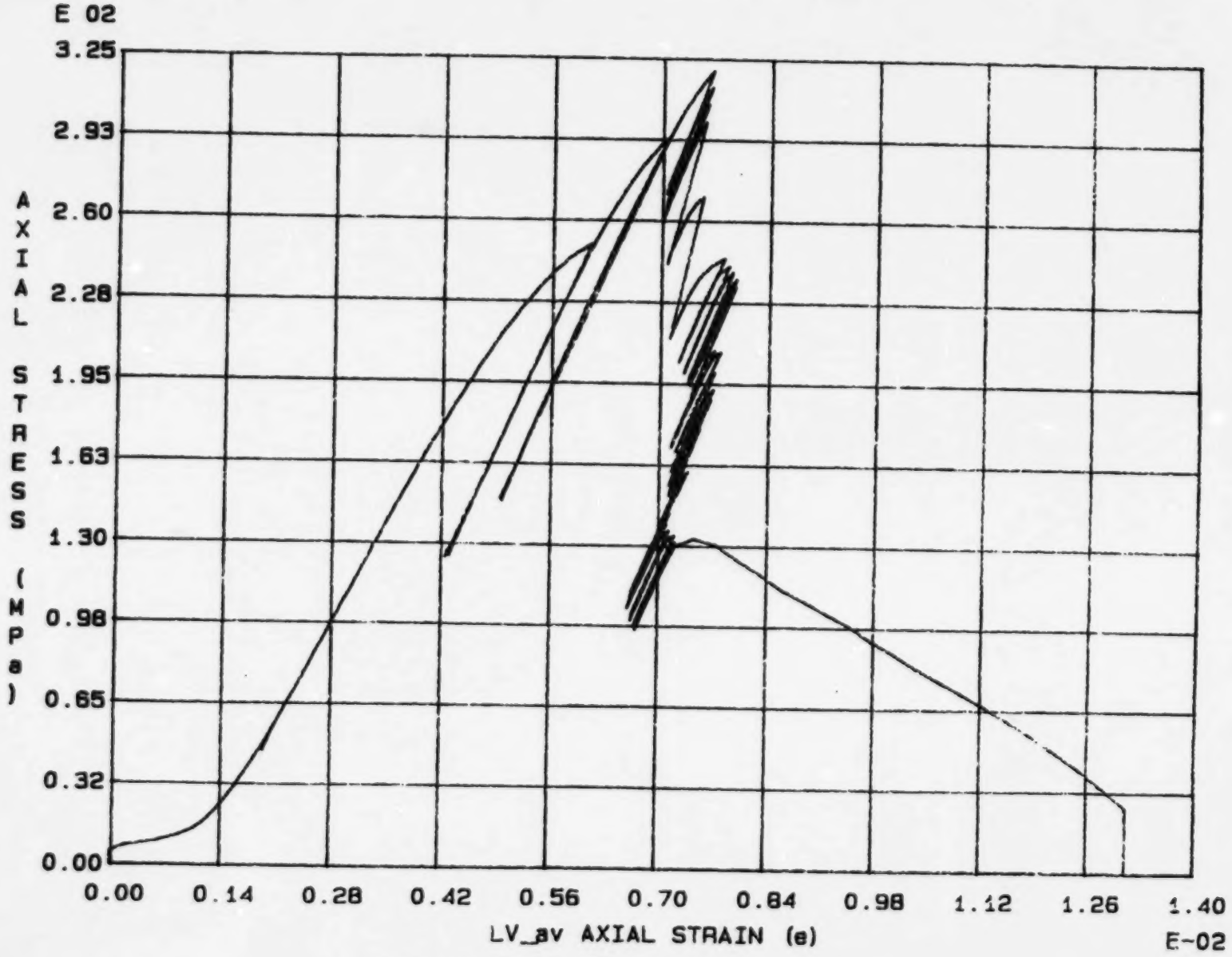

FIG.12 SPECIMEN Q3

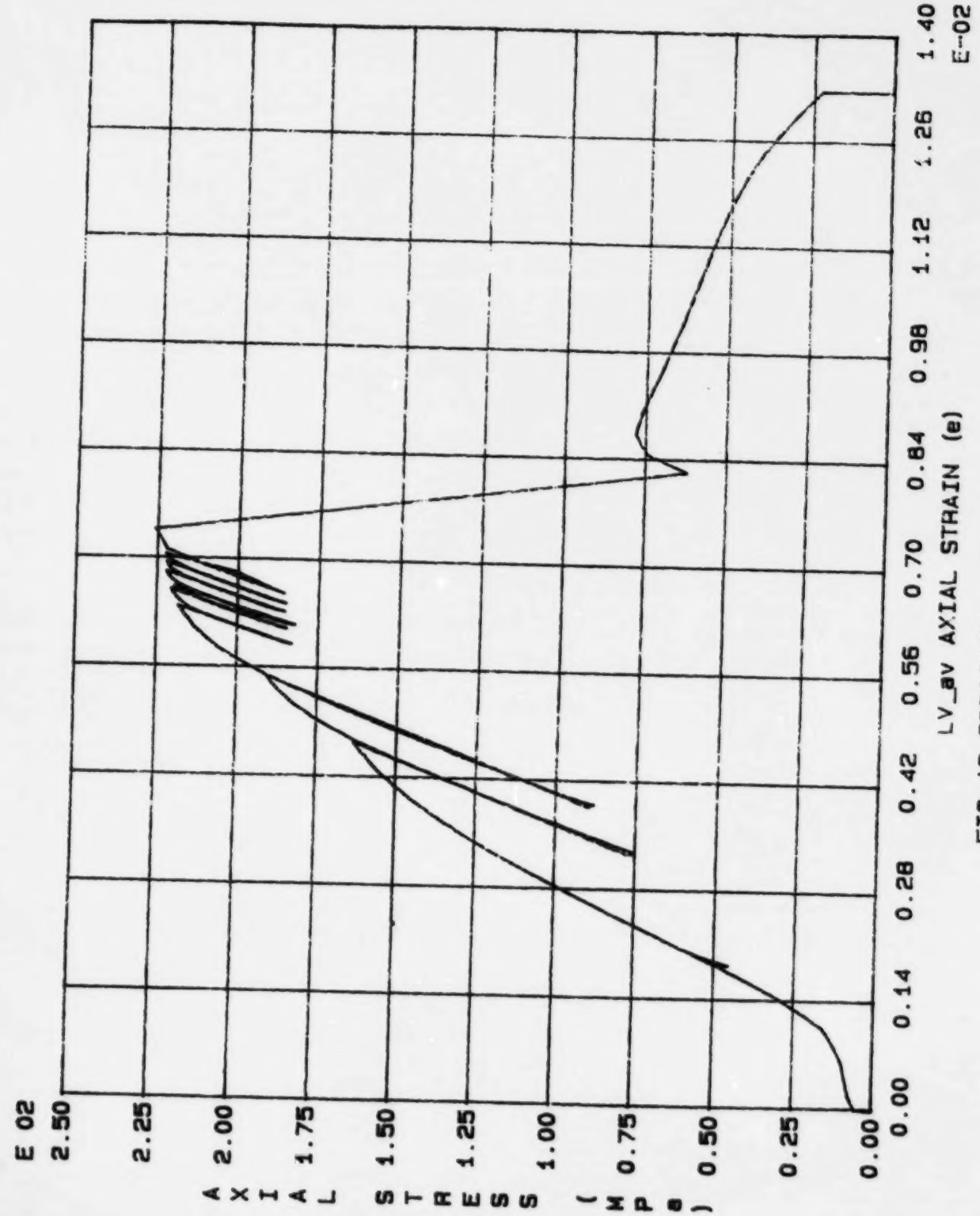

FIG.13 SPECIMEN Q5

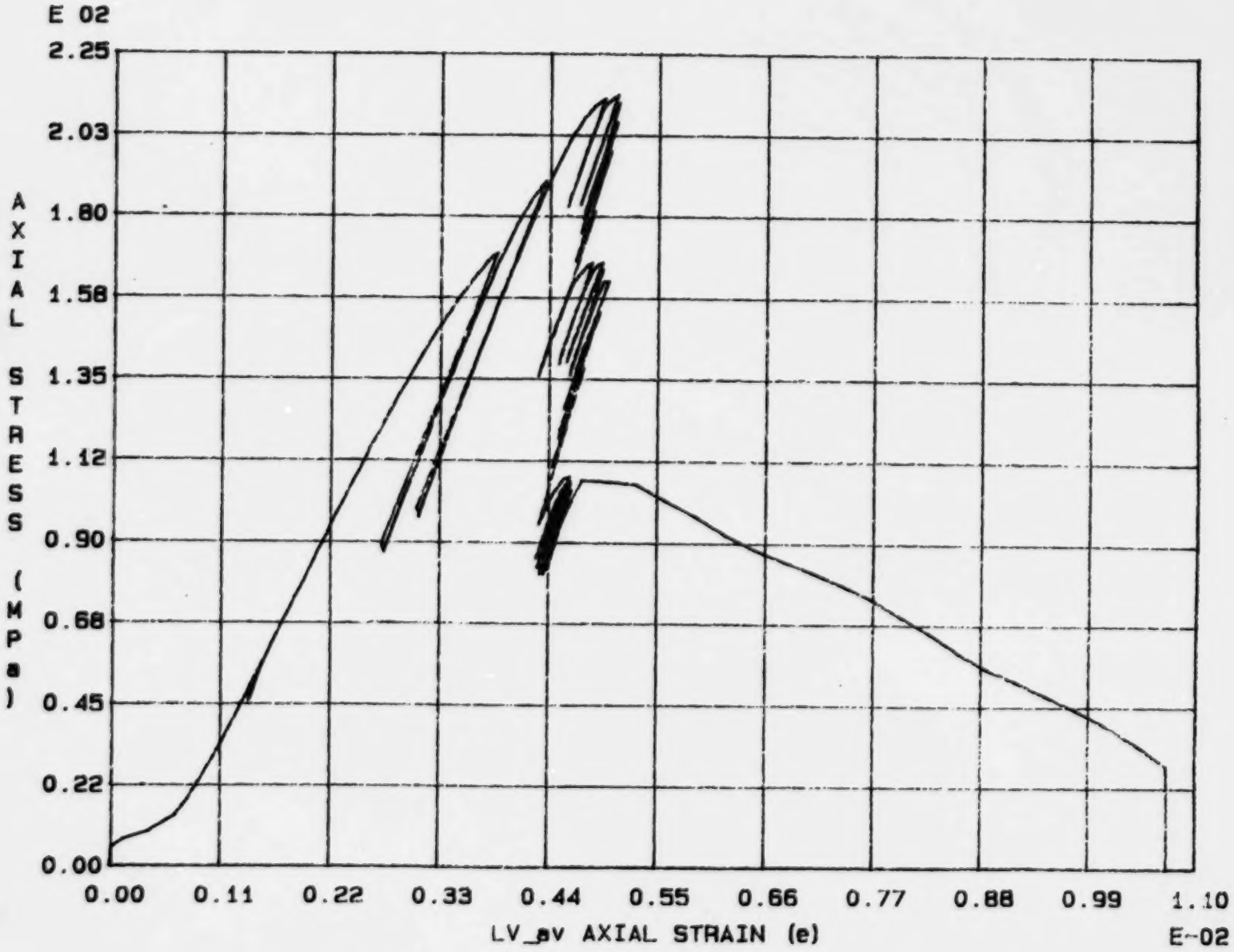

FIG.14 SPECIMEN 06

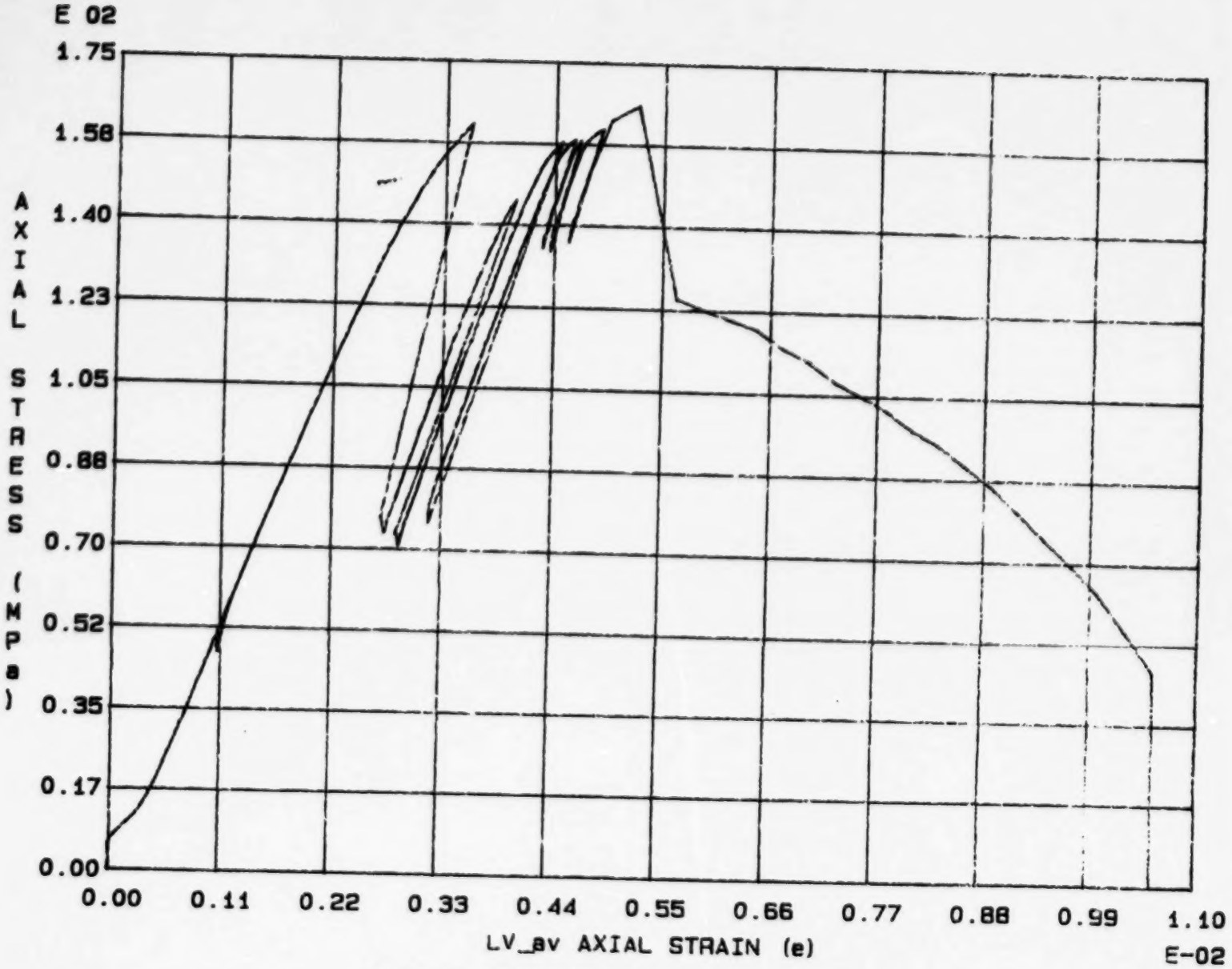

FIG.15 SPECIMEN P3

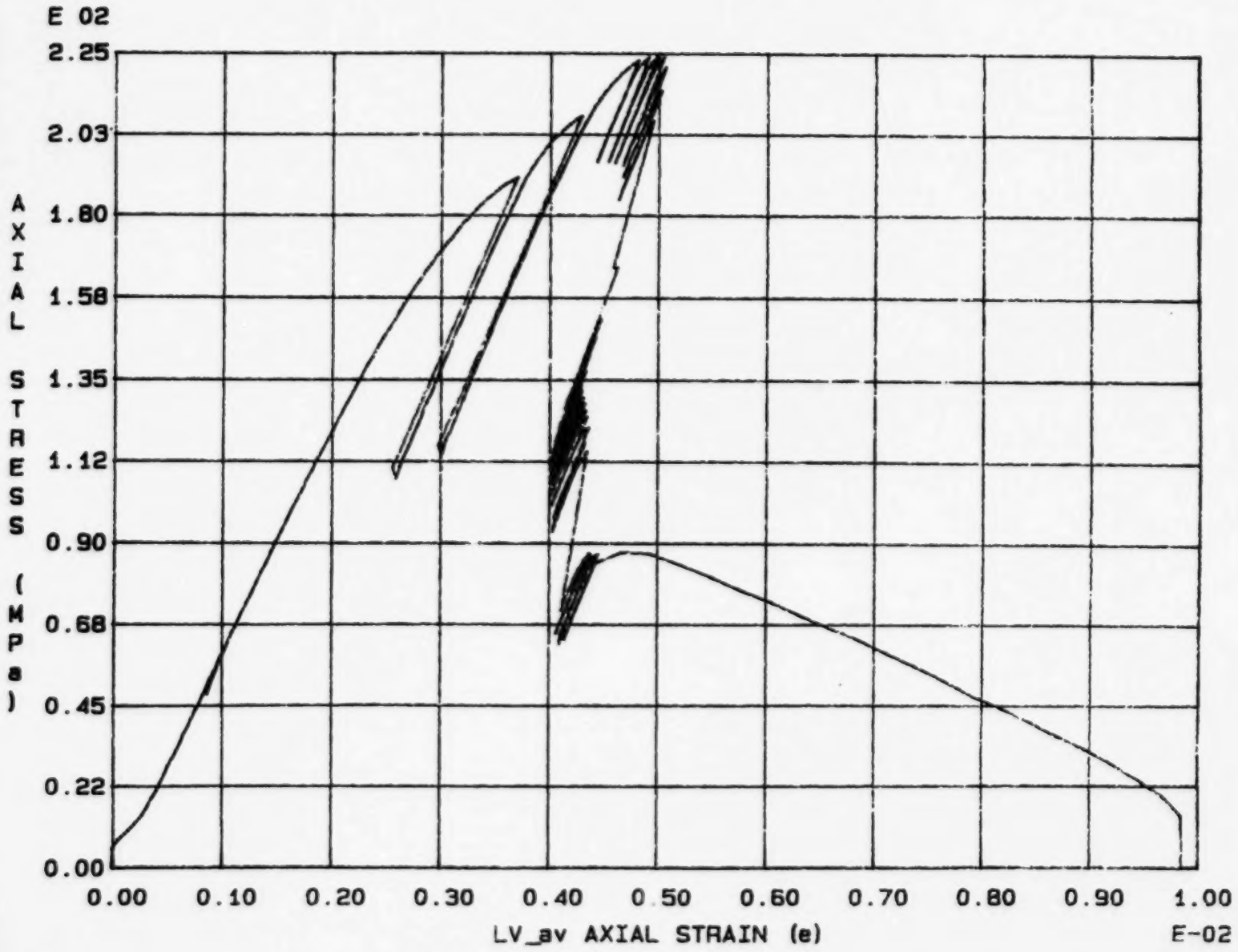

FIG.16 SPECIMEN P7

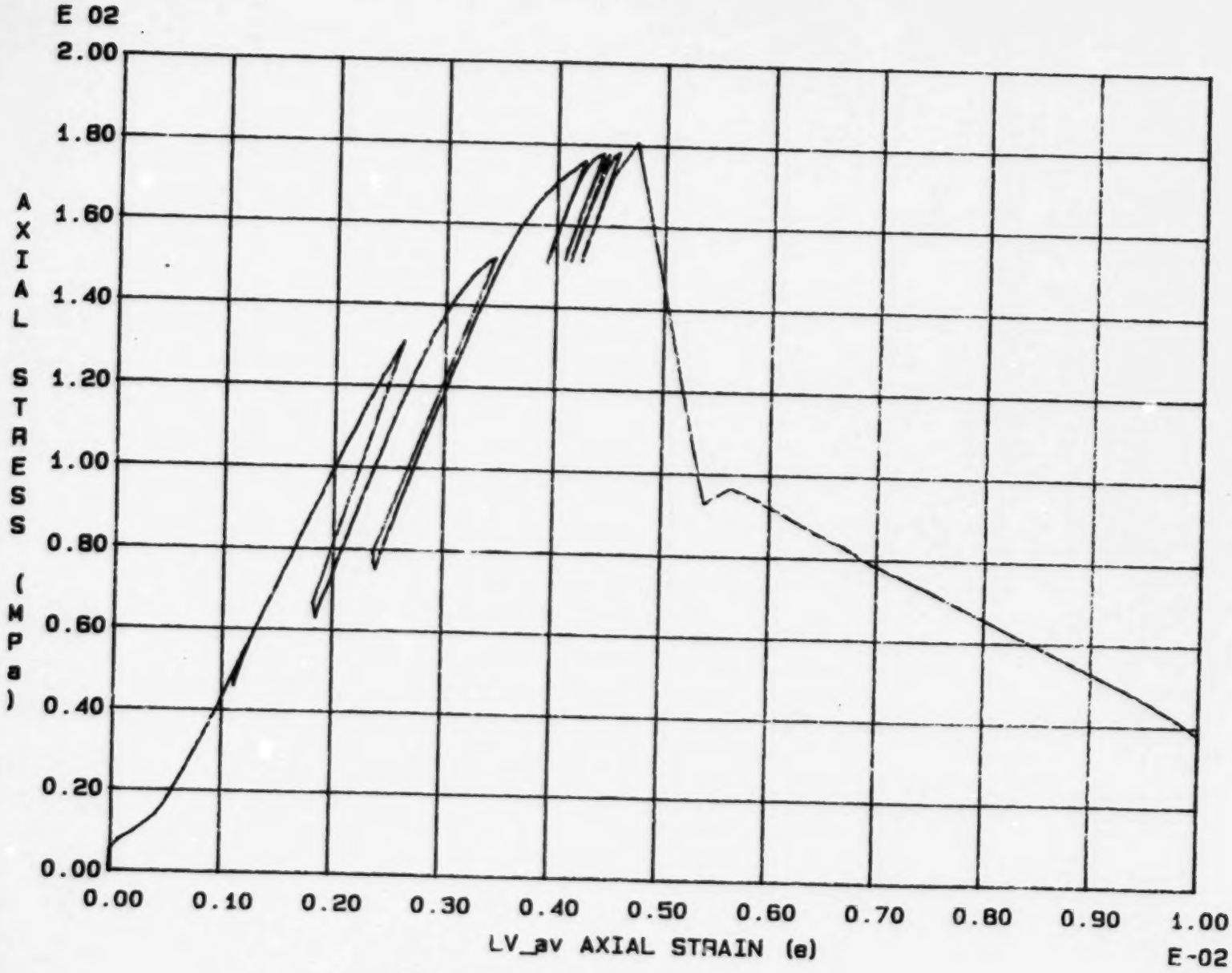

FIG.17 SPECIMEN P10

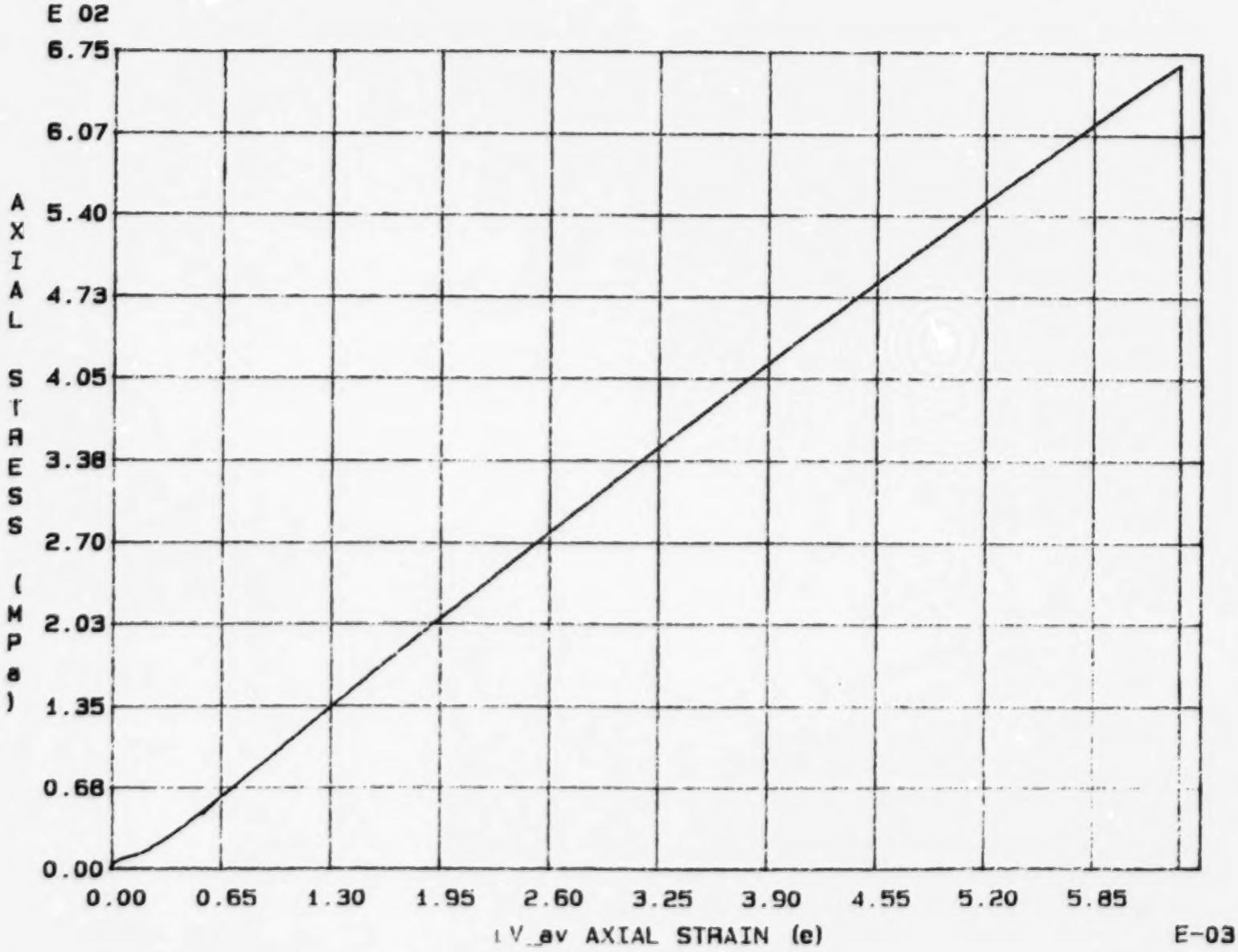

FIG.18 SPECIMEN 01

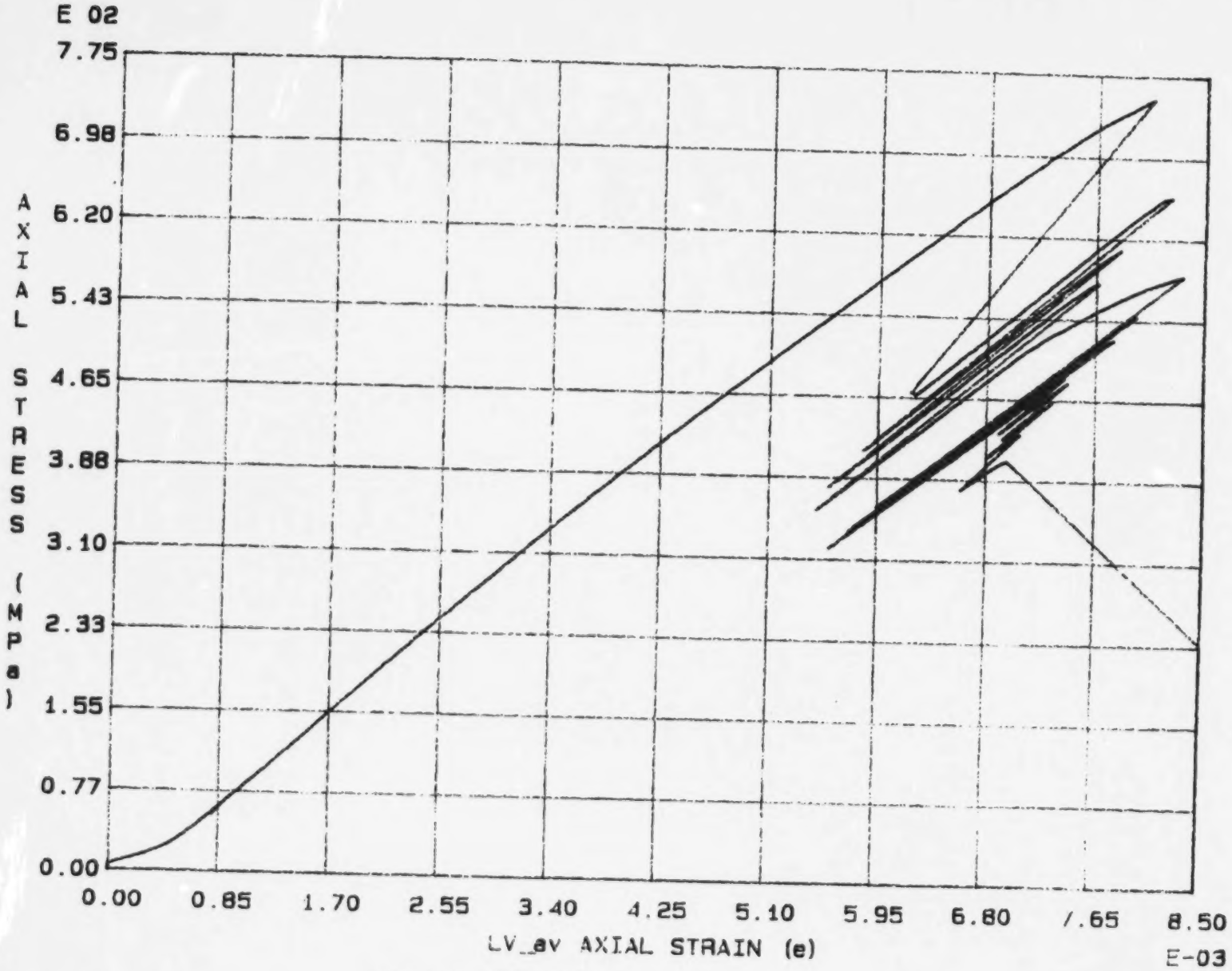

FIG.19 SPECIMEN 02

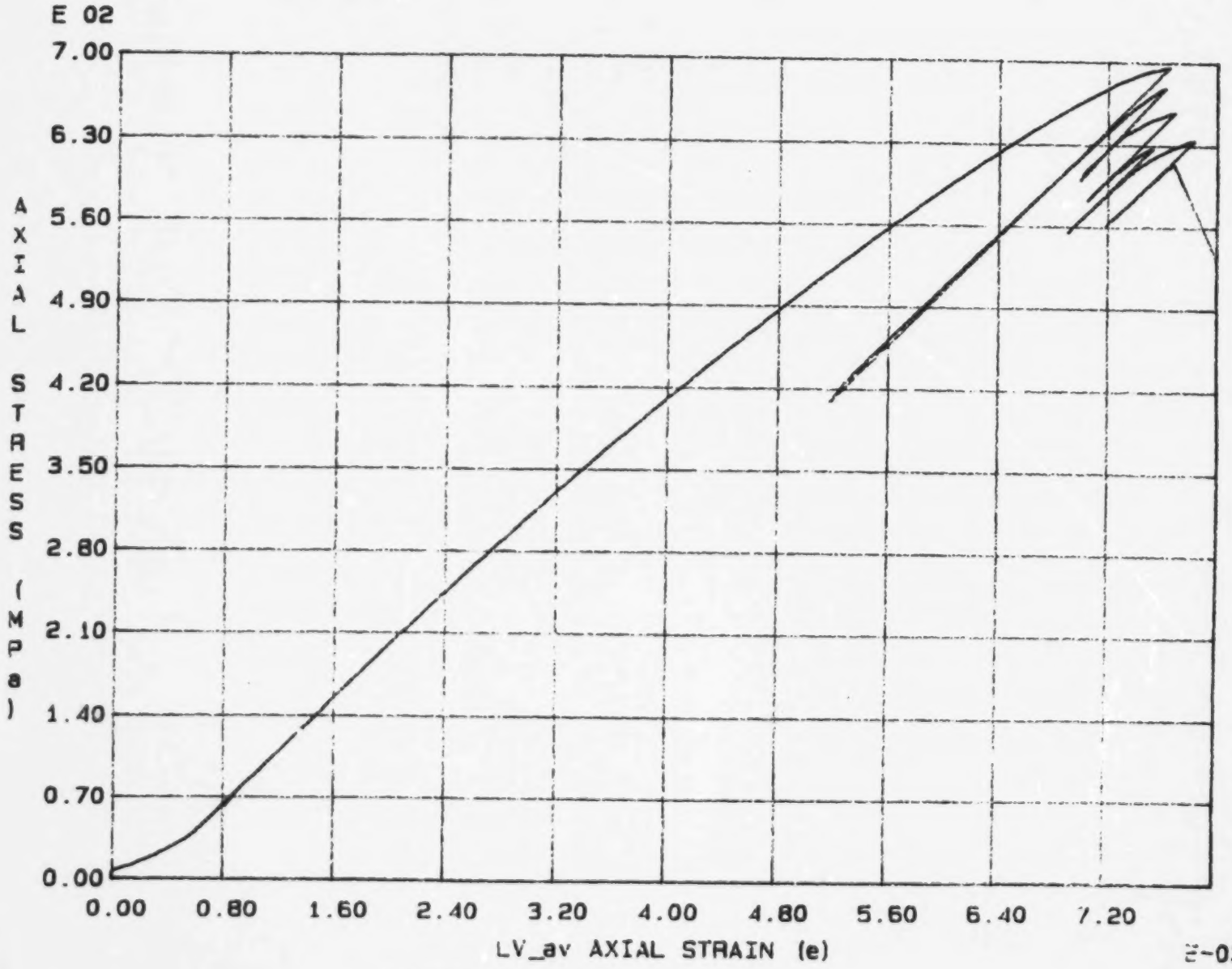

FIG.20 SPECIMEN 04